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Watanabe

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(54) **LENS APPARATUS AND IMAGE PROJECTION APPARATUS**

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G02B 15/14 (2006.01)

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(58) **Field of Classification Search** 359/694–704; 396/62, 72, 73, 75, 84, 85, 349; 348/340
See application file for complete search history.

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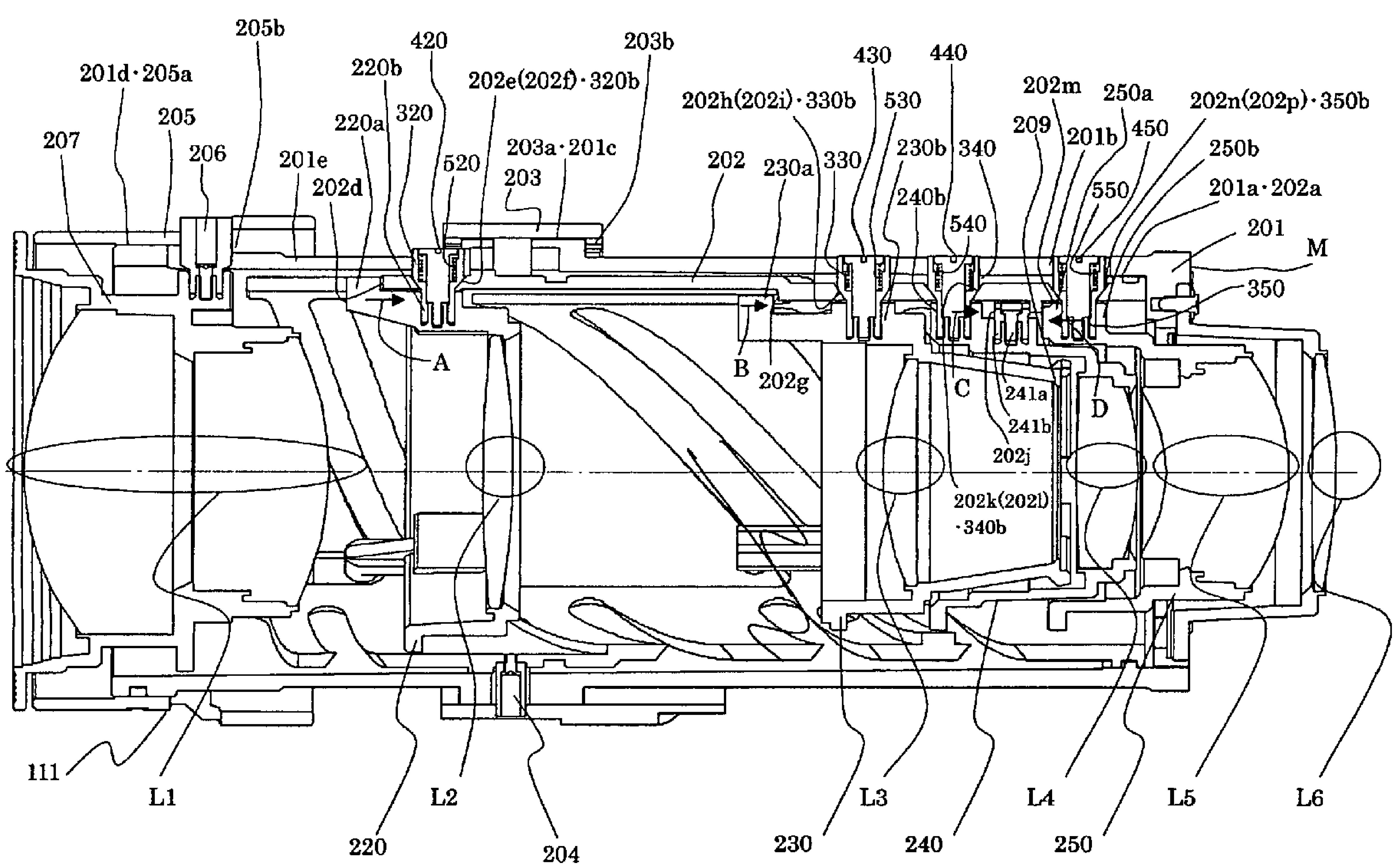
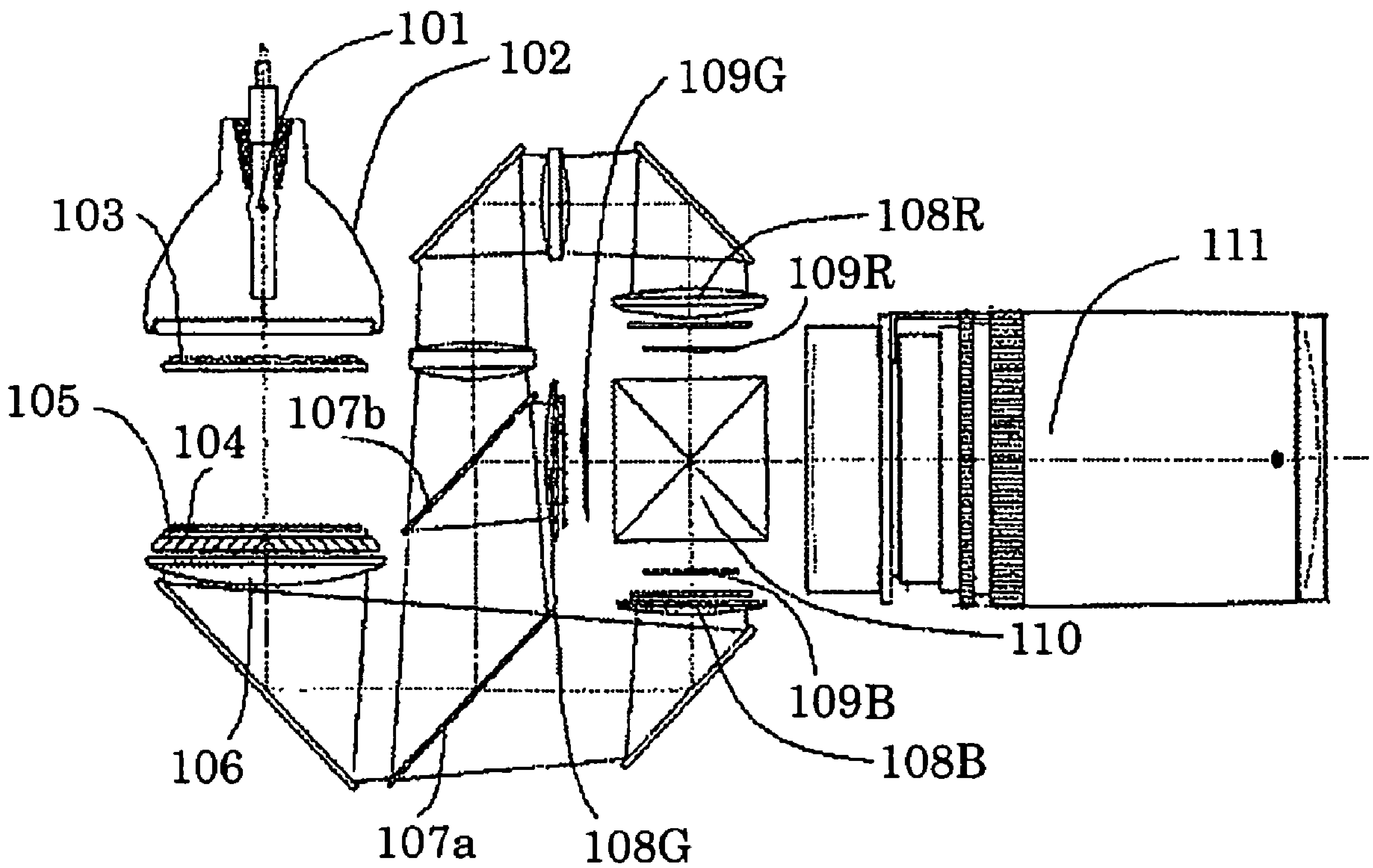
(57) **ABSTRACT**

The lens apparatus which includes a lens system, a cam barrel including a cam surface, and a moving barrel provided with a cam follower in contact with the cam surface and configured to be moved in a direction of an optical axis of the lens system by rotation of the cam barrel around the optical axis. The cam surface is parallel to a direction orthogonal to the optical axis. The cam barrel includes a tapered surface inclining with respect to the direction orthogonal to the optical axis. The moving barrel is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

6 Claims, 3 Drawing Sheets

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108R
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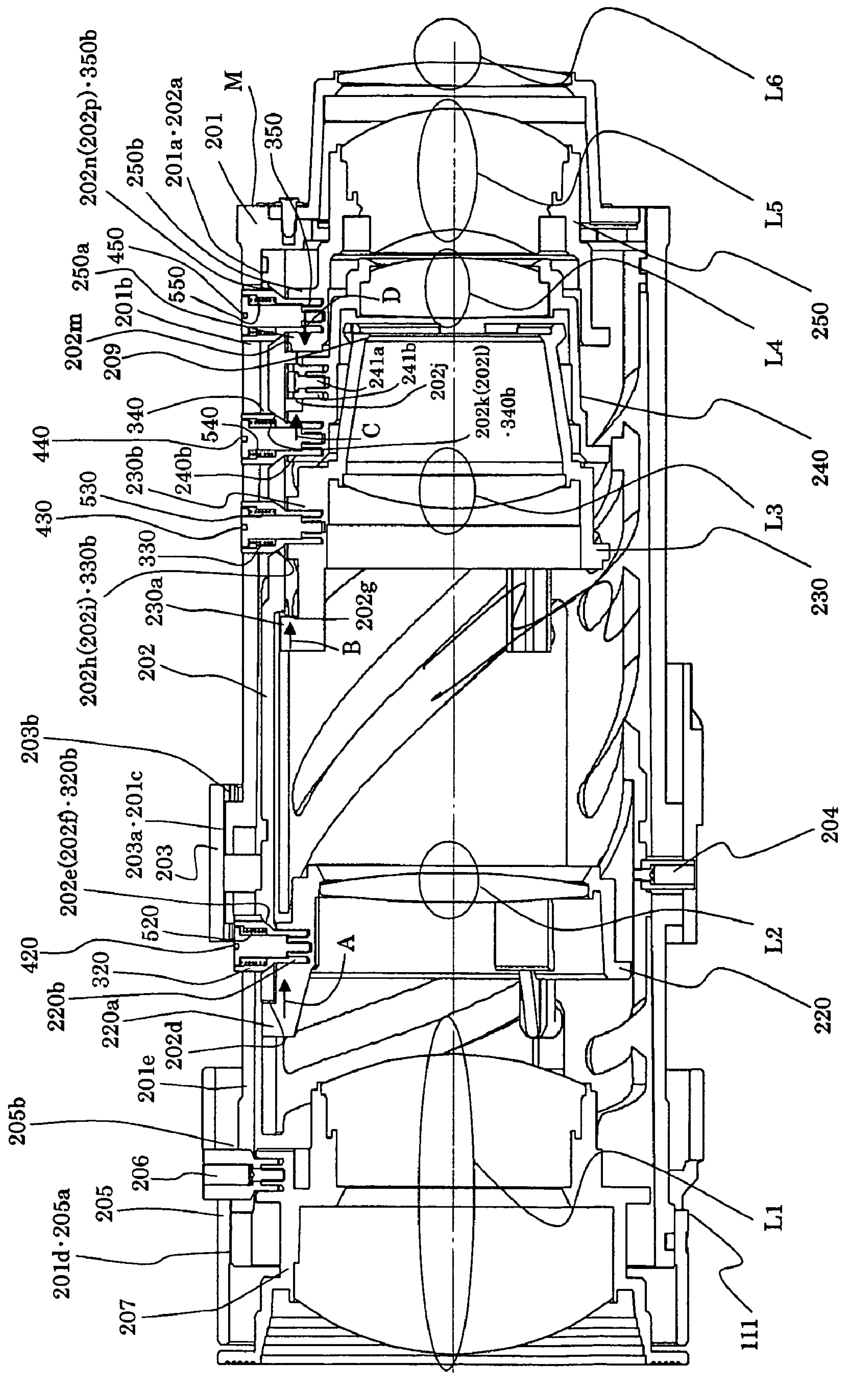
108B
107a
108G

FIG. 1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202j
202k(202l)
·340b
340
540
C
440
230b
240b
530
430
330
202h(202i)·330b
230a
202g
B
202
203b
202e(202f)·320b
203a·201c
203
520
420
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220b
220a
A
202d
201e
205b
206
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L6
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L4
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L3
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L2
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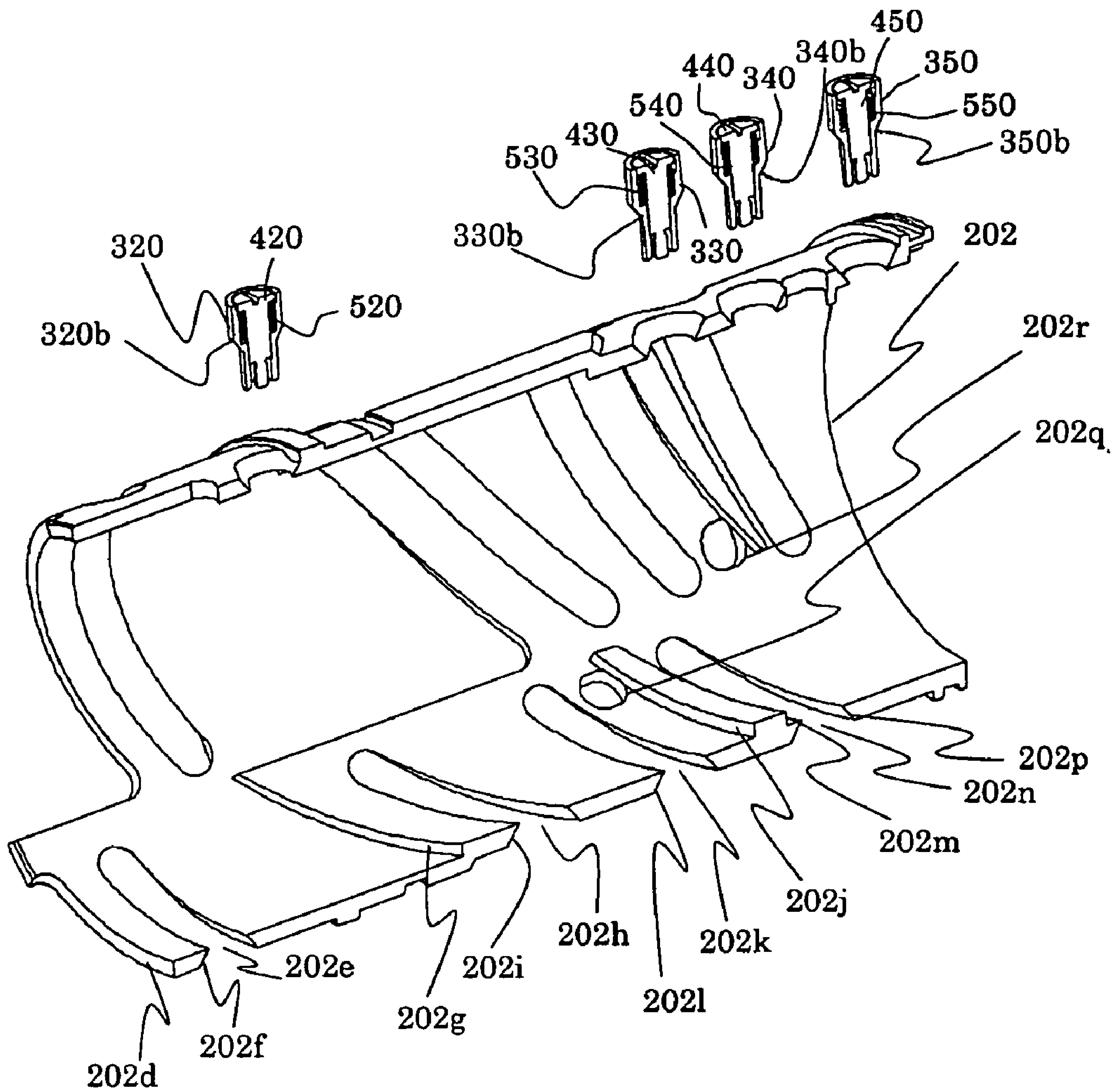
L1
111

FIG. 2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202f
202d

FIG. 3

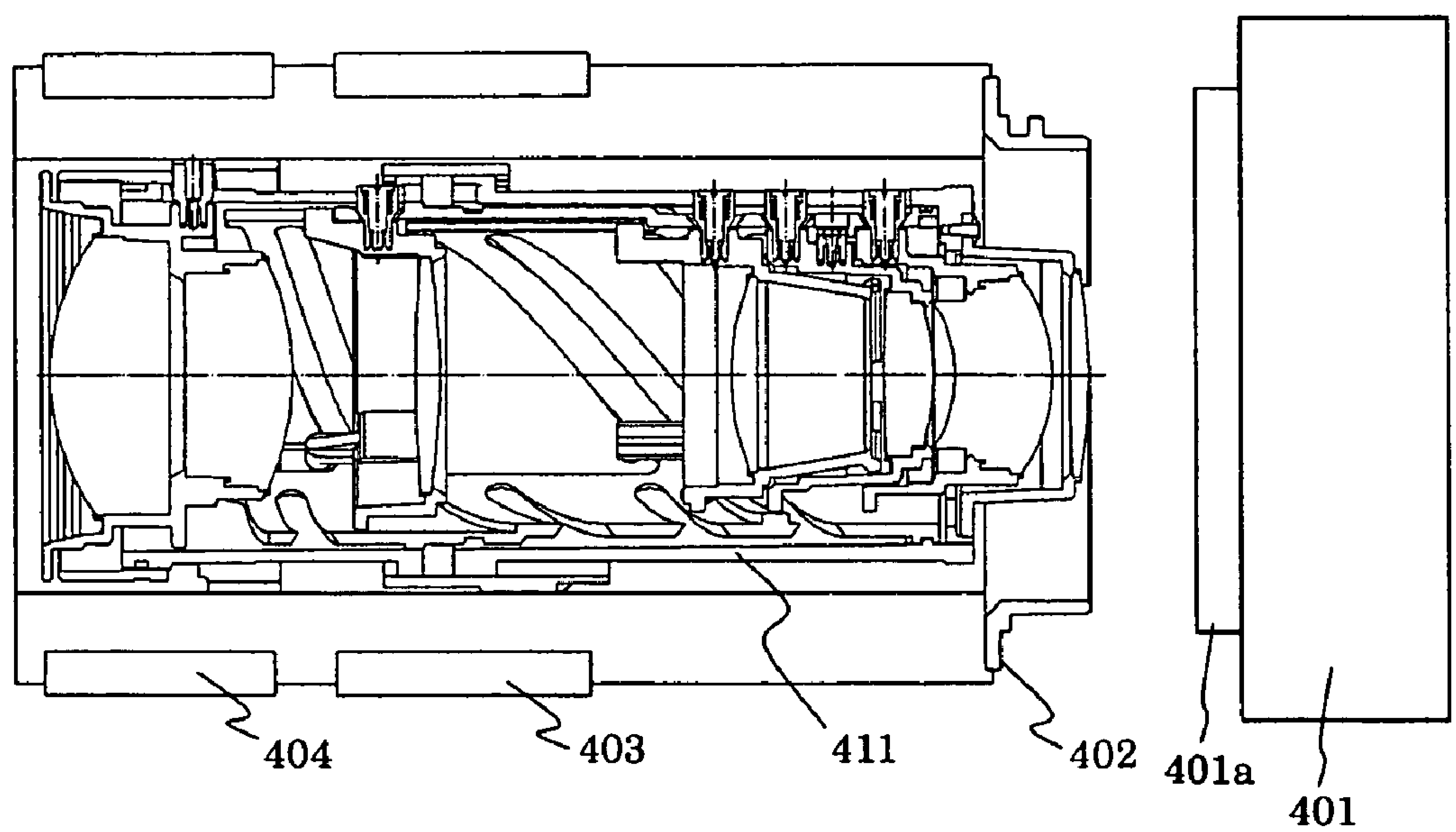
404
403
411
402
401a
401

FIG. 4

LENS APPARATUS AND IMAGE PROJECTION APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a lens apparatus in which two barrel members (for example, a cam barrel and a moving barrel) are relatively moved in an optical axis direction by a cam mechanism, the lens apparatus being suitable for, for example, a projection lens used in an image projection apparatus.

An image projection apparatus projects through a projection lens an enlarged image corresponding to an original image formed on an image-forming element (light-modulating element) such as a liquid crystal panel and a digital micromirror device (DMD) onto a screen. Such an image projection apparatus is demanded to improve positional accuracy of movable lens units in the projection lens in order to improve quality of the projected image. Therefore, in a projection lens in which the movable lens units are moved by a cam mechanism to perform zooming or focusing, it is necessary to reduce positional shifting, tilting and decentering of the movable lens units occurring due to backlash in the cam mechanism.

A projection lens disclosed in Japanese Patent Laid-Open No. 2006-235287 employs a configuration in which a spring is inserted into a tapered cam follower provided on a moving barrel and the spring biases the tapered cam follower toward a center of a tapered cam groove formed on a cam barrel.

A lens apparatus disclosed in Japanese Patent Laid-Open No. 2001-116975 employs a configuration in which two movable lens units are pulled by a spring disposed therebetween in directions approaching each other and thereby cam followers provided on the two movable lens units are pressed against cam surfaces formed on ends of a cam barrel in an optical axis direction.

A lens apparatus disclosed in Japanese Patent Laid-Open No. 2002-006196 employs a configuration in which a convex cam is formed on an outer circumferential surface of a cam barrel and the convex cam is sandwiched by two cam followers provided at two positions in an optical axis direction on an inner circumferential surface of a moving barrel such that phases of the two cam followers are mutually different.

Further, a lens apparatus disclosed in Japanese Patent Laid-Open No. 06-194555 employs a configuration in which an elastic member is attached to a cam follower inserted into a cam groove and the cam follower is pressed against an inner surface of the cam groove by an elastic force of the elastic member.

However, in the configuration disclosed in Japanese Patent Laid-Open No. 2006-235287, if mechanical accuracy of a surface of the cam groove is not extremely high, the moving barrel hung by the cam follower may be tilted or decentered with respect to an optical axis.

In the configuration disclosed in Japanese Patent Laid-Open No. 2001-116975, if a distance between the movable lens units pulled by the spring in the directions approaching each other, a pressing force of the cam follower against the cam surface is increased or decreased, thereby changing a rotational load (torque necessary for rotation) of the cam barrel.

In the configuration disclosed in Japanese Patent Laid-Open No. 2002-006196, low mechanical accuracy of the two cam followers sandwiching the convex cam may reduce smoothness of rotation of the cam barrel.

Further, in the configuration disclosed in Japanese Patent Laid-Open No. 06-194555, when the cam groove is manu-

factured, since a center of the cam follower and that of the cam groove are shifted from each other, the manufacturing becomes difficult.

SUMMARY OF THE INVENTION

The present invention provides a lens apparatus capable of reducing backlash in a cam mechanism having a configuration easily manufactured, thereby improving optical performance, and an image projection apparatus with the lens apparatus.

The present invention provides as one aspect thereof a lens apparatus which includes a lens system, a cam barrel including a cam surface, and a moving barrel provided with a cam follower in contact with the cam surface and configured to be moved in a direction of an optical axis of the lens system by rotation of the cam barrel around the optical axis. The cam surface is parallel to a direction orthogonal to the optical axis. The cam barrel includes a tapered surface inclining with respect to the direction orthogonal to the optical axis. The moving barrel is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

The present invention provides as another aspect thereof a lens apparatus which includes a lens system, a first barrel member including a cam surface, and a second barrel member provided with a cam follower in contact with the cam surface. The first and second barrel members are relatively moved in a direction of an optical axis of the lens system by relative rotation of the first and second barrel members around the optical axis. The cam surface is parallel to a direction orthogonal to the optical axis. The first barrel member includes a tapered surface inclining with respect to the direction orthogonal to the optical axis. The second barrel member is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

The present invention provides as further another aspect thereof an image projection apparatus which includes an image-forming element configured to form an original image, and the above-described lens apparatus configured to project light from the image-forming element onto a projection surface.

Other aspects of the present invention will become apparent from the following description and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a configuration of a projector using a projection lens barrel that is Embodiment 1 of the present invention.

FIG. **2** is a cross-sectional view of the projection lens barrel.

FIG. **3** is an oblique cross-sectional view of a cam barrel and a tapered follower which constitute part of the projection lens barrel.

FIG. **4** is a schematic view of an interchangeable lens that is Embodiment 2 of the present invention.

DESCRIPTION OF THE EMBODIMENTS

Exemplary embodiments of the present invention will be described hereinafter with reference to the accompanying drawings.

Embodiment 1

FIG. **1** shows a configuration of an image projection apparatus (projector) including a projection lens barrel (lens apparatus) **111** that is a first embodiment (Embodiment 1) of the present invention.

Non-polarized white light from a light source (lamp) **101** is converted into a collimated light flux by a parabolic reflector **102** and then enters a first fly-eye lens **103**. The collimated light flux is divided into plural light fluxes by the first fly-eye lens **103**, and the plural divided light fluxes then enter a second fly-eye lens **104**. Each divided light flux from the second fly-eye lens **104** is converted into a light flux having a specific polarization direction by a polarization conversion element **105**, and the polarized light flux then enters a condenser lens **106**. The condenser lens **106** overlaps the plural divided light fluxes on each of liquid crystal panels **109**R, **109**G and **109**B to illuminate each liquid crystal panel with a homogeneous light intensity distribution.

Each divided light flux (polarized light) emerging from the condenser lens **106** is color-separated into three color light components of R, G and B by dichroic mirrors **107***a* and **107***b*. The color light components of R, G and B enter the liquid crystal panels **109**R, **109**G and **109**B through field lenses **108**R, **108**G and **108**B, respectively. The liquid crystal panels **109**R, **109**G and **109**B are transmissive image-forming elements (light-modulating elements). On the liquid crystal panels **109**R, **109**G and **109**B, original images corresponding to an input image to the projector are formed.

The three color light components image-modulated by the liquid crystal panels **109**R, **109**G and **109**B are combined into image light by a color combination prism **110**. The combined image light is enlarged and projected onto a screen (projection surface, not shown) by a lens system in a projection lens barrel **111**.

Although this embodiment uses the transmissive liquid crystal panel, a reflective liquid crystal panel and a DMD (digital micromirror device) may be used as an image-forming element.

Next, description will be made of a configuration of the projection lens barrel **111** with reference to FIGS. **2** and **3**. FIG. **2** shows a section of the projection lens barrel **111**, and FIG. **3** shows an oblique section of a cam barrel and a pressing mechanism which constitute part of the projection lens barrel **111**.

In these figures, reference character L**1** denotes a first lens unit having a negative power (refractive power), and reference character L**2** denotes a second lens unit having a positive power. Reference character L**3** denotes a third lens unit having a positive power, and reference character L**4** denotes a fourth lens unit having a negative power. Reference character L**5** denotes a fifth lens unit having a positive power, and reference character L**6** denotes a sixth lens unit having a positive power. The first to sixth lens units L**1** to L**6** constitute a lens system (projection optical system). In the following description, the left side (first lens unit side) of FIG. **2** is referred to as "screen side", and the right side (sixth lens unit side) thereof is referred to as "panel side".

The first to fifth lens units L**1** to L**5** are movable lens units that are movable in a direction of an optical axis of the lens system (hereinafter referred to as "optical axis direction"). The sixth lens unit L**6** is a fixed lens unit that is not moved in the optical axis direction. The first to fifth lens units L**1** to L**5** are moved in the optical axis direction so as to vary distances thereamong to perform zooming (variation of magnification) and focusing.

A mount portion M is provided at a panel side end of a fixed barrel **201** that constitutes a main body of the projection lens barrel **111**. The mount portion M is fixed to a prism base (not shown) that holds optical elements such as the color combination prism **110** with screws.

At an inner circumferential part of the fixed barrel **201**, a cam barrel holding portion **201***a* into which an outer circumferential portion **202***a* of a cam barrel **202** is incorporated is formed. The fixed barrel **201** holds at the cam barrel holding portion **201***a* the cam barrel **202** rotatably around the optical axis of the lens system. Moreover, the fixed barrel **201** holds the sixth lens unit L**6** at its panel side end (end closer to the panel than the mount portion M).

In the cam barrel **202**, cam portions for moving the second to fifth lens units L**2** to L**5** in the optical axis direction are formed. The cam barrel **202** is a resin molding member. The cam barrel **202** corresponds to a first barrel member.

Reference numeral **220** denotes a second lens barrel which holds the second lens unit L**2**. Reference numeral **230** denotes a third lens barrel which holds the third lens unit L**3**. Reference numeral **240** denotes a fourth lens barrel which holds the fourth lens unit L**4**. Reference numeral **250** denotes a fifth lens barrel which holds the fifth lens unit L**5**. Each of the second to fifth lens barrels **220** to **250** corresponds to a moving barrel and a second barrel member.

A cam surface **202***d* for moving the second lens barrel **220** is formed at a screen side end face of the cam barrel **202**. The cam surface **202***d* is formed as a surface parallel to a direction orthogonal to the optical axis (that is, parallel to a radial direction of the cam barrel **202**). A cam follower **220***a* integrally formed on the second lens barrel **220** is in contact with the cam surface **202***d* in the optical axis direction.

Moreover, a guide groove portion **202***e* extending parallel to the cam surface **202***d* is formed in the cam barrel **202**. The cases where the guide groove portion **202***e* is parallel to the cam surface **202***d* include not only a case where the guide groove portion **202***e* is completely parallel to the cam surface **202***d*, but also a case where the guide groove portion **202***e* has a certain parallelism with the cam surface **202***d*. This is applied to other guide groove portions described later.

At both sides of the guide groove portion **202***e* in its width direction corresponding to the optical axis direction, tapered surfaces **202***f* inclining with respect to the direction orthogonal to the optical axis such that a distance therebetween decreases toward an inner side in the radial direction of the cam barrel **202**. The cam follower **220***a* of the second lens barrel **220** is disposed on an opposite side (screen side) to that of the guide groove portion **202***e* (that is, that of a taper follower **320** described later) with respect to the cam surface **202***d* in the optical axis direction.

A hole portion **220***b* is formed on an outer circumferential part of the second lens barrel **220**. A tapered follower **320** is inserted into the hole portion **220***b* so as to be movable in the direction orthogonal to the optical axis. A mounting shaft **420** is disposed at a central portion of the tapered follower **320**, and is screwed (fixed) to the second lens barrel **220**.

Between the mounting shaft **420** and the tapered follower **320**, a spring (biasing member) **520** is disposed which biases the tapered follower **320** toward the inner side in the radial direction of the cam barrel **202**.

The mounting shaft **420** and the tapered follower **320** are inserted into the guide groove portion **202***e*. A tapered surface **320***b* of the tapered follower **320** biased toward the inner side in the radial direction of the cam barrel **202** by a biasing force of the spring **520** is pressed against the tapered surfaces **202***f* of the guide groove portion **202***e*.

The distance between the tapered surfaces **202***f* on both sides of the guide groove portion **202***e* and an outer diameter of the tapered surface **320***b* of the tapered follower **320** respectively decrease (become smaller) toward the inner side in the radial direction of the cam barrel **202**. Therefore, the second lens barrel **220** is held at a position where a center of the mounting shaft **420** and tapered follower **320** coincides with a center of the guide groove portion **202***e* in its width direction. This configuration biases the cam follower **220***a* mounted on the second lens barrel **220** toward the panel side as shown by an arrow A to always press the cam follower **220***a* against the cam surface **202***d* in the optical axis direction.

A cylindrical portion of the tapered follower **320** also engages with a straight groove portion **201***b* formed in the fixed barrel **201** so as to extend in the optical axis direction. This engagement prevents rotation of the second lens barrel **220** around the optical axis.

Thus, a lift of the cam surface **202***d* of the cam barrel **202** rotating around the optical axis moves the second lens barrel **220** in the optical axis direction.

A cam surface **202***g* for moving the third lens barrel **230** is formed on an inner circumferential part of the cam barrel **202**, the cam surface **202***g* having a smaller inner diameter than that of the cam surface **202***d* for moving the second lens barrel **220**. The cam surface **202***g* is also parallel to the direction orthogonal to the optical axis. The cam follower **230***a* formed integrally with the third lens barrel **230** is in contact with the cam surface **202***g* in the optical axis direction.

Moreover, a guide groove portion **202***h* extending parallel to the cam surface **202***g* is formed on the cam barrel **202**.

On both sides of the guide groove portion **202***h* in its width direction, tapered surfaces **202***i* are formed which incline with respect to the direction orthogonal to the optical axis such that a distance therebetween decreases toward the inner side in the radial direction of the cam barrel **202**. The cam follower **230***a* of the third lens barrel **230** is disposed on an opposite side (screen side) to that of the guide groove portion **202***h* (that is, that of a tapered follower **330** described later) with respect to the cam surface **202***g* in the optical axis direction.

A hole portion **230***b* is formed on an outer circumferential part of the third lens barrel **230**. The tapered follower **330** is inserted into the hole portion **230***b* so as to be movable in the direction orthogonal to the optical axis. A mounting shaft **430** is disposed at a central portion of the tapered follower **330**, and is screwed (fixed) to the third lens barrel **230**.

Between the mounting shaft **430** and the tapered follower **330**, a spring **530** is disposed which biases the tapered follower **330** toward the inner side in the radial direction of the cam barrel **202**.

The mounting shaft **430** and the tapered follower **330** are inserted into the guide groove portion **202***h*. A tapered surface **330***b* of the tapered follower **330** biased toward the inner side in the radial direction of the cam barrel **202** by a biasing force of the spring **530** is pressed against the tapered surfaces **202***i* of the guide groove portion **202***h*.

The distance between the tapered surfaces **202***i* on both sides of the guide groove portion **202***h* and an outer diameter of the tapered surface **330***b* of the tapered follower **330** respectively decrease (become smaller) toward the inner side in the radial direction of the cam barrel **202**. Therefore, the third lens barrel **230** is held at a position where a center of the mounting shaft **430** and tapered follower **330** coincides with the center of the guide groove portion **202***h* in its width direction. This configuration biases the cam follower **230***a* mounted on the third lens barrel **230** toward the panel side as shown by an arrow B to always press the cam follower **230***a* against the cam surface **202***g* in the optical axis direction.

A cylindrical portion of the tapered follower **330** also engages with the straight groove portion **201***b* formed in the fixed barrel **201**. This engagement prevents rotation of the third lens barrel **230** around the optical axis.

Thus, a lift of the cam surface **202***g* of the cam barrel **202** rotating around the optical axis moves the third lens barrel **230** in the optical axis direction.

An eccentric cam follower **241***b* is mounted on the fourth lens barrel **240**. The eccentric cam follower **241***b* is inserted into an insertion hole formed on the fourth lens barrel **240**, and is fixed to the fourth lens barrel **240** with a screw **241***a*. A center of the eccentric cam follower **241***b* is eccentric (decentered) with respect to a center of the screw **241***a*.

A cam surface **202***j* for moving the fourth lens barrel **240** is formed on the inner circumferential part of the cam barrel **202**, the cam surface **202***j* having a smaller inner diameter than that of the cam surface **202***g* for moving the third lens barrel **230**. The cam surface **202***j* is also parallel to the direction orthogonal to the optical axis.

Moreover, a guide groove portion **202***k* extending parallel to the cam surface **202***j* is formed on the cam barrel **202**.

On both sides of the guide groove portion **202***k* in its width direction, tapered surfaces **202***l* are formed which incline with respect to the direction orthogonal to the optical axis such that a distance therebetween decreases toward the inner side in the radial direction of the cam barrel **202**. The eccentric cam follower **241***b* mounted on the fourth lens barrel **240** is disposed on a same side (screen side) as that of the guide groove portion **202***k* (that is, that of a tapered follower **340** described later) with respect to the cam surface **202***j* in the optical axis direction.

A hole portion **240***b* is formed on an outer circumferential part of the fourth lens barrel **240**. The tapered follower **340** is inserted into the hole portion **240***b* so as to be movable in the direction orthogonal to the optical axis. A mounting shaft **440** is disposed at a central part of the tapered follower **340**, and is screwed (fixed) to the fourth lens barrel **240**.

Between the mounting shaft **440** and the tapered follower **340**, a spring **540** is disposed which biases the tapered follower **340** toward the inner side in the radial direction of the cam barrel **202**.

The mounting shaft **440** and the tapered follower **340** are inserted into the guide groove portion **202***k*. A tapered surface **340***b* of the tapered follower **340** biased toward the inner side in the radial direction of the cam barrel **202** by a biasing force of the spring **540** is pressed against the tapered surfaces **202***l* of the guide groove portion **202***k*.

The distance between the tapered surfaces **202***l* on both sides of the guide groove portion **202***k* and an outer diameter of the tapered surface **340***b* of the tapered follower **340** respectively decrease (become smaller) toward the inner side in the radial direction of the cam barrel **202**. Therefore, the fourth lens barrel **240** is held at a position where a center of the mounting shaft **440** and tapered follower **340** coincides with a center of the guide groove portion **202***k* in its width direction. This configuration biases the eccentric cam follower **241***b* mounted on the fourth lens barrel **240** toward the panel side as shown by an arrow C to always press the eccentric cam follower **241***b* against the cam surface **202***j* in the optical axis direction.

A cylindrical portion of the tapered follower **340** also engages with the straight groove portion **201***b* formed in the fixed barrel **201**. This engagement prevents rotation of the fourth lens barrel **240** around the optical axis.

Thus, a lift of the cam surface **202***j* of the cam barrel **202** rotating around the optical axis moves the fourth lens barrel **240** in the optical axis direction.

On the cam barrel **202**, holes **202***q* and **202***r* are formed at two places through which the eccentric cam follower **241***b* mounted on the fourth lens barrel **240** can be seen from the outside of the cam barrel **202**. On a head portion of the eccentric cam follower **241***b*, a rotation adjustment groove is formed. A tool (not shown) inserted from the outside of the fixed barrel **201** through the straight groove portion **201***b* formed on the fixed barrel **201** and the holes **202***q* and **202***r* formed on the cam barrel **202** is engaged with the rotation adjustment groove, and then the eccentric cam follower **241***b* is eccentrically rotated around the screw **241***a*. This enables angle adjustment of the fourth lens barrel **240** to improve optical performance of the projection lens barrel **111** which may deteriorate due to manufacturing errors thereof.

A cam surface **202***m* for moving the fifth lens barrel **250** is formed on the inner circumferential part of the cam barrel **202**, the cam surface **202***m* having a substantially same inner diameter as that of the cam surface **202***j* for moving the fourth lens barrel **240**. The cam surface **202***m* is also parallel to the direction orthogonal to the optical axis. The cam follower **250***a* formed integrally with the fifth lens barrel **250** is in contact with the cam surface **202***m* in the optical axis direction.

Moreover, a guide groove portion **202***n* extending parallel to the cam surface **202***m* is formed on the cam barrel **202**.

On both sides of the guide groove portion **202***n* in its width direction, tapered surfaces **202***p* are formed which incline with respect to the direction orthogonal to the optical axis such that a distance therebetween decreases toward the inner side in the radial direction of the cam barrel **202**. The cam follower **250***a* mounted on the fifth lens barrel **250** is disposed on a same side (panel side) as that of the guide groove portion **202***n* (that is, that of a tapered follower **350** described later) with respect to the cam surface **202***m* in the optical axis direction.

A hole portion **250***b* is formed on an outer circumferential part of the fifth lens barrel **250**. The tapered follower **350** is inserted into the hole portion **250***b* so as to be movable in the direction orthogonal to the optical axis. A mounting shaft **450** is disposed at a central portion of the tapered follower **350**, and is screwed (fixed) to the fifth lens barrel **250**.

Between the mounting shaft **450** and the tapered follower **350**, a spring **550** is disposed which biases the tapered follower **350** toward the inner side in the radial direction of the cam barrel **202**.

The mounting shaft **450** and the tapered follower **350** are inserted into the guide groove portion **202***n*. A tapered surface **350***b* of the tapered follower **350** biased toward the inner side in the radial direction of the cam barrel **202** by a biasing force of the spring **550** is pressed against the tapered surfaces **202***p* of the guide groove portion **202***n*.

The distance between the tapered surfaces **202***p* on both sides of the guide groove portion **202***n* and an outer diameter of the tapered surface **350***b* of the tapered follower **350** respectively decrease (become smaller) toward the inner side in the radial direction of the cam barrel **202**. Therefore, the fifth lens barrel **250** is held at a position where a center of the mounting shaft **450** and tapered follower **350** coincides with a center of the guide groove portion **202***n* in its width direction. This configuration biases the cam follower **250***a* mounted on the fifth lens barrel **250** toward the screen side as shown by an arrow D to always press the cam follower **250***a* against the cam surface **202***m* in the optical axis direction.

A cylindrical portion of the tapered follower **350** also engages with the straight groove portion **201***b* formed in the fixed barrel **201**. This engagement prevents rotation of the fifth lens barrel **250** around the optical axis.

Thus, a lift of the cam surface **202***m* of the cam barrel **202** rotating around the optical axis moves the fifth lens barrel **250** in the optical axis direction.

As described above, each of the second to fifth lens barrels **220** to **250** is provided with the pressing mechanism constituted by the mounting shaft, the tapered follower and the spring. The biasing force generated in the optical axis direction by the pressing mechanism always presses the cam follower of each lens barrel against the cam surface, which reduces backlash in the cam mechanism for moving each lens barrel. This configuration enables highly accurate control of the position of each lens barrel in the optical axis direction with the cam surface, and enables suppression of tilting of each lens barrel with respect to the optical axis.

Further, the plural cam surfaces formed for the second to fifth lens barrels (moving barrels) **220** to **250** on the cam barrel **202** include the cam surface (first cam surface) **202***d* having a largest inner diameter among the plural cam surfaces and the cam surface (second cam surface) **202***m* having a smallest inner diameter thereamong. The cam surface **202***d* having the largest inner diameter is formed closest to the screen (at a most-screen side) among the plural cam surfaces. Moreover, the cam surface **202***m* having the smallest inner diameter is formed closest to the panel (at a most-panel side) among the plural cam surfaces.

Further, in the second lens barrel **220** provided with the cam follower **220***a* in contact with the cam surface (one of the first and second cam surfaces) **202***d*, the cam follower **220***a* is located on the opposite side to that of the tapered follower **320** with respect to the cam surface **202***d* in the optical axis direction. This configuration presses the cam follower **220***a* against the cam surface **202***d* such that the cam follower **220***a* is drawn to a tapered follower **320** side.

Moreover, in the fifth lens barrel **250** provided with the cam follower **250***a* in contact with the cam surface (the other of the first and second cam surfaces) **202***m*, the cam follower **250***a* is located on the same side as that of the tapered follower **350** with respect to the cam surface **202***m* in the optical axis direction. This configuration presses the cam follower **250***a* against the cam surface **202***m* such that the cam follower **250***a* is pressed from the tapered follower **320** side.

The above configuration makes it possible to use the both end faces of the cam barrel **202** in the optical axis direction as the cam surfaces **202***d* and **202***m*, thereby enabling efficient arrangement of the cam surfaces on the cam barrel **202** even when distances among the plural lens units are narrow.

In addition, this embodiment includes two cam surfaces **202***j* and **202***m* as cam surfaces having the smallest inner diameter among the plural cam surfaces formed on the cam barrel **202**. Then, two cam followers **241***b* and **250***a* in contact with the two cam surfaces **202***j* and **202***m* are pressed against the two cam surfaces **202***j* and **202***m* in directions (shown by the arrows C and D) facing each other.

This configuration makes it possible to increase the inner diameters of the cam surfaces **202***j* and **202***m* formed on the inner circumferential part of the cam barrel **202**, which enables formation of an enough space for accommodating the third to fifth lens barrels **230** to **250** inside the cam barrel **202**. In other words, this configuration makes it possible to suppress increase of the outer diameter of the cam barrel **202**, and that of the projection lens barrel **111**.

On the outer circumferential part of the fixed barrel **201**, a zoom ring holding portion **201***c* on which an inner circumferential part **203***a* of a zoom ring **203** is mounted is formed. The fixed barrel **201** holds the zoom ring **203** rotatably around the optical axis at the zoom ring holding portion **201***c*. The zoom ring **203** is mounted to the fixed barrel **201** with a bayonet structure. The bayonet structure holds the zoom ring **203** rotatably with respect to the fixed barrel **201** while preventing the zoom ring **203** from moving in the optical axis direction.

A groove portion **203***b* extending in the optical axis direction is formed on the zoom ring **203**. A cam follower **204** which is screwed on the cam barrel **202** engages with the groove portion **203***b*.

In this configuration, rotation of the zoom ring **203** around the optical axis with respect to the fixed barrel **201** rotates the cam barrel **202** around the optical axis. The rotation of the cam barrel **202** moves the second to fifth lens barrels **220** to **250** in the optical axis direction, and thereby the zooming is performed. The zoom ring **203** is rotated by a driving force generated by a motor (not shown) or a manual operation of a user.

On the outer circumferential part of the fixed barrel **201**, a focus ring holding portion **201***d* on which an inner circumferential part **205***a* of a focus ring **205** is mounted is formed. The fixed barrel **201** holds the focus ring **205** rotatably around the optical axis at the focus ring holding portion **201***d*. The focus ring **205** is mounted to the fixed barrel **201** with a bayonet structure. The bayonet structure holds the focus ring **205** rotatably with respect to the fixed barrel **201** while preventing the focus ring **205** from moving in the optical axis direction.

On the focus ring **205**, a cam surface **205***b* for moving the first lens barrel **207** holding the first lens unit L**1** in the optical axis direction is formed. The cam surface **205***b* is formed in parallel with the direction orthogonal to the optical axis. A cam follower **206** mounted on the first lens barrel **207** is in contact with the cam surface **205***d* in the optical axis direction. The cam follower **206** also engages with a straight groove portion **201***e* formed on the fixed barrel **201** so as to extend in the optical axis direction.

In this configuration, rotation of the focus ring **205** around the optical axis with respect to the fixed barrel **201** moves the first lens barrel **207** in the optical axis direction, and thereby the focusing is performed. The focus ring **205** is rotated by a driving force generated by a motor (not shown) or a manual operation of a user.

The third lens barrel **230** is provided with an aperture stop **209** disposed between the third lens unit L**3** and the fourth lens unit L**4**. The aperture stop **209** is moved in the optical axis direction together with the third lens barrel **230**.

Embodiment 2

Although Embodiment 1 described the projection lens barrel used for the image projection apparatus, a lens apparatus according to the present invention can be used as an image-taking lens apparatus for a camera (image pickup apparatus).

FIG. **4** shows an interchangeable lens apparatus **411**, which is a second embodiment (Embodiment 2) of the present invention, used for image taking with a camera **401**. The interchangeable lens apparatus **411** of this embodiment uses the configuration described in Embodiment 1 for moving the first to fifth lens barrel in the optical axis direction.

The camera **401** has a mount portion **401***a* with which a mount portion **402** of the interchangeable lens apparatus **411** is coupled. The coupling makes it possible to perform image taking by a camera system constituted by the camera **401** and the interchangeable lens apparatus **411**.

The interchangeable lens apparatus **411** is provided with a zoom operation ring **403** corresponding to the zoom ring described in Embodiment 1 and a focus operation ring **404** corresponding to the focus ring described in Embodiment 1.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all modifications, equivalent structures and functions.

For example, Embodiment 1 described the case where the cam barrel **202** is rotated at a fixed position in the optical axis direction and the second to fifth lens barrels **220** to **250** are moved in the optical axis direction with respect to the cam barrel **202**. However, the present invention can be applied to any lens apparatuses in which a first barrel member including a cam surface and a second barrel member provided with a cam follower in contact with the cam surface are relatively rotated, and thereby the first and second barrel members are relatively moved in the optical axis direction. In other words, in embodiments of the present invention, a barrel member rotating around the optical axis may be any one or both of the first and second barrel members, and a barrel member moving in the optical axis direction may also be any one or both of the first and second barrel members.

Moreover, although the description was made of the case where the eccentric cam follower is provided to the fourth lens barrel in the above embodiments, a cam follower may be provided integrally with the fourth lens barrel as in the other lens barrels.

This application claims the benefit of Japanese Patent Application No. 2008-145193, filed on Jun. 2, 2008, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. A lens apparatus comprising:
a lens system;
a cam barrel including a cam surface; and
a moving barrel provided with a cam follower in contact with the cam surface, the moving barrel being configured to be moved in a direction of an optical axis of the lens system by rotation of the cam barrel around the optical axis,
wherein the cam surface is parallel to a direction orthogonal to the optical axis,
wherein the cam barrel includes a tapered surface inclining with respect to the direction orthogonal to the optical axis, and
wherein the moving barrel is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

2. A lens apparatus according to claim **1**,
wherein the lens apparatus comprises a plurality of the moving barrels,

wherein the cam barrel includes a plurality of the cam surfaces, the cam followers respectively provided for the moving barrels being in contact with the respective cam surfaces,

wherein the cam surfaces includes a first cam surface having a largest inner diameter among the cam surfaces and a second cam surface having a smallest inner diameter among the cam surfaces,

wherein, in the moving barrel provided with the cam follower in contact with one cam surface of the first and second cam surfaces, the cam follower is disposed on an opposite side to that of the tapered follower with respect to the one cam surface in the direction of the optical axis, and

wherein, in the moving barrel provided with the cam follower in contact with the other cam surface of the first and second cam surfaces, the cam follower is disposed on a same side as that of the tapered follower with respect to the other cam surface in the direction of the optical axis.

3. A lens apparatus according to claim **1**,

wherein the lens apparatus comprises a plurality of the moving barrels,

wherein the cam barrel includes a plurality of the cam surfaces, the cam followers respectively provided for the moving barrels being in contact with the respective cam surfaces,

wherein the cam surfaces includes two cam surfaces having a smallest inner diameter among the cam surfaces, and

wherein two of the cam followers in contact with the two cam surfaces are pressed against the two cam surfaces in directions facing each other.

4. A lens apparatus comprising:

a lens system;

a first barrel member including a cam surface; and

a second barrel member provided with a cam follower in contact with the cam surface,

wherein the first and second barrel members are relatively moved in a direction of an optical axis of the lens system by relative rotation of the first and second barrel members around the optical axis,

wherein the cam surface is parallel to a direction orthogonal to the optical axis,

wherein the first barrel member includes a tapered surface inclining with respect to the direction orthogonal to the optical axis, and

wherein the second barrel member is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

5. An image projection apparatus comprising:

an image-forming element configured to form an original image; and

a lens apparatus configured to project light from the image-forming element onto a projection surface,

wherein the lens apparatus comprises:

a lens system;

a cam barrel including a cam surface; and

a moving barrel provided with a cam follower in contact with the cam surface, the moving barrel being configured to be moved in a direction of an optical axis of the lens system by rotation of the cam barrel around the optical axis,

wherein the cam surface is parallel to a direction orthogonal to the optical axis,

wherein the cam barrel includes a tapered surface inclining with respect to the direction orthogonal to the optical axis, and

wherein the moving barrel is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

6. An image projection apparatus comprising:

an image-forming element configured to form an original image; and

a lens apparatus configured to project light from the image-forming element onto a projection surface,

wherein the lens apparatus comprises:

a lens system;

a first barrel member including a cam surface; and

a second barrel member provided with a cam follower in contact with the cam surface,

wherein the first and second barrel members are relatively moved in a direction of an optical axis of the lens system by relative rotation of the first and second barrel members around the optical axis,

wherein the cam surface is parallel to a direction orthogonal to the optical axis,

wherein the first barrel member includes a tapered surface inclining with respect to the direction orthogonal to the optical axis, and

wherein the second barrel member is provided with a tapered follower in contact with the tapered surface and a pressing mechanism configured to bias the tapered follower in the direction orthogonal to the optical axis so as to press the tapered follower against the tapered surface to thereby press the cam follower against the cam surface in the direction of the optical axis.

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